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Gamma transitions in the decay of La^{142}

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With 5 figures in the text

ABSTRACT

The half-lives of the isotopes La^{141} and La^{142}, first reported as fission products by Hahn and Strassmann, are found to be (3.76 ± 0.10) h and (81 ± 3) m compared with the figures 3.7 h and 77 m given by Katcoff. The gamma rays of 0.63 MeV and 0.87 MeV found by Vanden Bosch in the decay of La^{142} are verified. Six new gamma rays with the energies 1.0, 1.8, 2.0, 2.4, 2.9 and 3.4 MeV are found by measurements with a 4-in × 4-in NaI(Tl) crystal. Coincidence investigations are carried out and a preliminary level scheme is given for Ce^{142}, the daughter nucleus of La^{142}.

The lanthanum used in these experiments was separated from fission products of uranium. About one gram of uranyl nitrate was irradiated for 10 minutes in the Swedish reactor R 1 (about $2 \cdot 10^{11}$ neutrons/cm^2 sec). As soon as possible (in less than 5 minutes) after the end of the irradiation the active barium was chemically isolated and purified by precipitations. The sample was then allowed to decay for 10 minutes and the lanthanum grown in was separated. Practically, the only remaining isotopes were then La^{141} and La^{142}. According to Duffield and Langer [1] (cf. also Katcoff [2]) only one gamma ray appears in the decay of La^{141}. Due to the low intensity of this gamma ray, the energy determination is very uncertain (1.3 to 1.6 MeV [1]). Our experiments do not confirm nor do they disprove the existence of such a gamma ray, but they show that any gamma ray possibly existing in the decay of La ^{141} must undoubtedly be very weak. Thus it is possible to study the spectrum of the gamma rays from the radioactive decay of La^{142} with a source obtained as described above.

Half-life measurements

The isotope classification of the high energy gamma rays given in the next section is partly made on the basis of the rate with which their intensities decrease. Therefore the half-lives of the two isotopes were redetermined. The half-life of La^{142} is earlier given by Hahn and Strassmann [3] as 74 m and by Katcoff [2] as 77 m. The half-life of La^{141} is reported by the same authors as 3.5 h and 3.7 h respectively.

For the half-life measurements an end window Geiger-Müller counter was used. This detector operated within a guard ring of counters in anticoincidence, thus reducing the background to about two counts per minute. Fig. 1 shows a decay curve recorded from a lanthanum source with this counter connected to an automatic

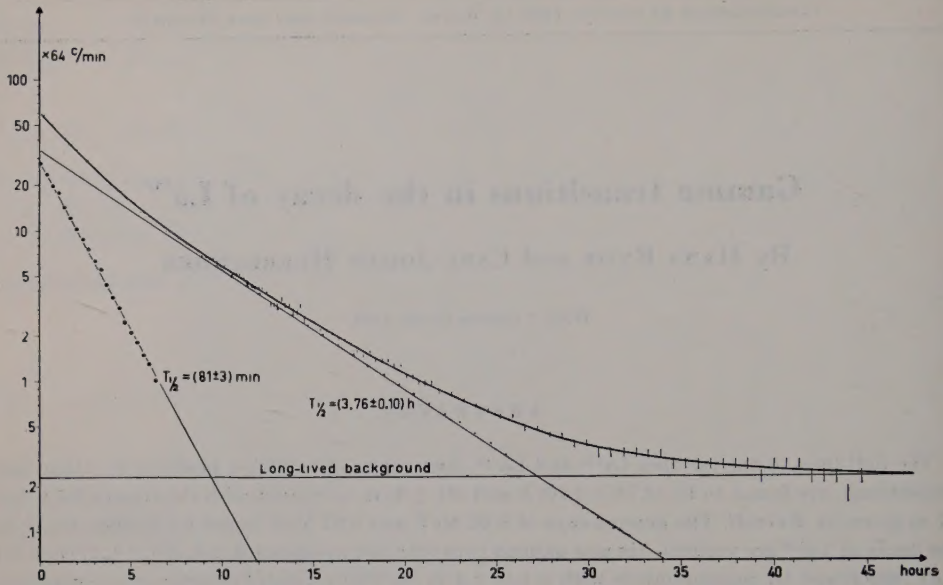

Fig. 1. Decay curve of a lanthanum source containing La^{141} (3.76 h), La^{142} (81 m) and a long-lived component, probably Ce^{141} (33 d). The points were measured with an automatic device giving every 64th pulse. Thus the real positions of the points may be anywhere along the vertical lines given in the figure. No statistical errors are given.

device. The components giving the best fit to the experimental curve are also shown in this figure. The half-lives of the two actual isotopes are found to be:

$$T_{1/2}(\mathrm{La}^{142}) = (81 \pm 3)\ \mathrm{m}$$

and

$$T_{1/2}(\mathrm{La}^{141}) = (3.76 \pm 0.10)\ \mathrm{h}$$

in good agreement with the earlier measurements.

Singles gamma spectrum

The decay of La^{142} to its daughter nucleus Ce^{142} gives rise to a complex beta and gamma spectrum. According to Vanden Bosch [4] the maximum energy of the beta spectrum is greater than 2.5 MeV and the gamma spectrum contains two gamma rays with the energies 0.630 MeV and 0.870 MeV.

In these experiments the gamma radiation was studied in a scintillation spectrometer with a 4-in × 4-in NaI(Tl) crystal, shielded with about ten centimeters of lead. The pulses obtained from the photomultiplier were analyzed with a multi-channel pulse height analyzer of the Hutchinson-Scarrott [5] type. The radiation from the radioactive source placed some centimeters outside the shield was well collimated. Moreover, a graphite layer, about one centimeter thick, was placed between the source and the detector to absorb the beta rays.

The singles gamma spectrum following the decay of La^{142} obtained with this

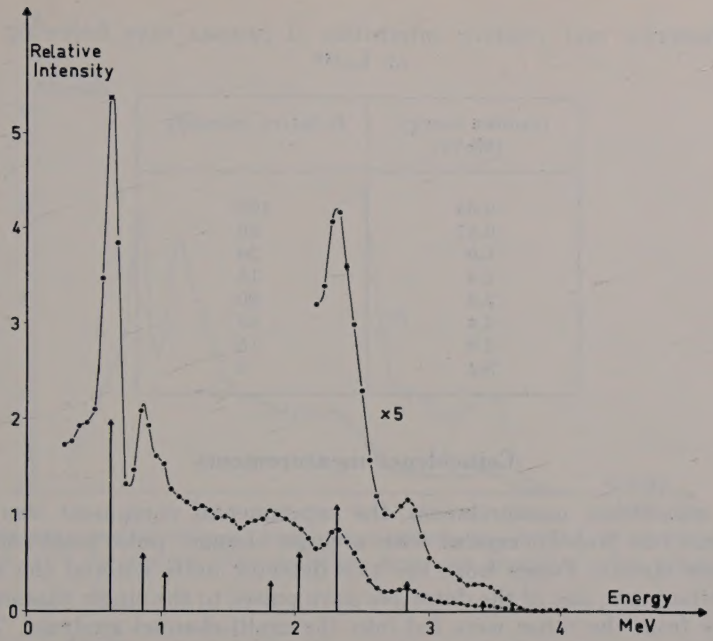

Fig. 2. Singles gamma spectrum following the decay of La^{142}. The background has been subtracted. The arrows indicate the positions of the photo-peaks and their heights give the relative intensities of the gamma rays. The statistical errors are given for a few points.

spectrometer is shown in Fig. 2. Knowing the resolving power of the scintillation spectrometer, an attempt has been made to resolve some parts of the singles spectrum into photo-peaks and Compton distributions. In this way the following gamma ray energies are obtained: 0.63, 0.87, 1.0, 1.8, 2.0, 2.4, 2.9 and 3.4 MeV. The energy of the 2.0 MeV gamma ray, which is difficult to determine from the singles spectrum in Fig. 2, is rather well settled in the coincidence spectrum shown in Fig. 4. Most of the energies are estimated to be accurate to within a few per cent. However, the energies of the 1.0 MeV and 1.8 MeV gamma rays are more uncertain. Between 1.0 MeV and 1.8 MeV there is also a region which has been impossible to analyze. It may be observed that this region should contain the weak gamma ray obtained from the decay of La^{141}, unavoidably present in the sample. A bump in the singles spectrum slightly above 3 MeV may possibly indicate a weak gamma ray with this energy.

Out of the singles spectrum resolved into photo-peaks, it is possible to determine the relative intensities of the gamma rays from the areas of the photo-peaks and the peak efficiency of the crystal. From an extrapolation of an empirical formula for the photofraction and from the values of the crystal efficiency given by Berger and Doggett [6], the peak efficiency of the 4-in × 4-in NaI(Tl) crystal has been obtained. To get a check of this response function we have used two photo-peaks in a radioactive decay, where the relative intensities are well known. Two nuclides were used for this purpose, namely Na^{22} and Na^{24}. The two pairs of points fitted the calculated curve very well. The values of the relative intensities of the gamma rays thus obtained must, of course, be treated with reservation. The values of the energies and the relative intensities of the gamma rays in the decay of La^{142} are given in Table 1.

Table 1. Energies and relative intensities of gamma rays following the decay of La^{142}.

Gamma energy (MeV)	Relative intensity
0.63	100
0.87	30
1.0	20
1.8	15
2.0	30
2.4	55
2.9	15
3.4	5

Coincidence measurements

For the coincidence measurements, the experimental equipment was completed with a $1\frac{3}{4}$-in × 1-in NaI(Tl) crystal with a single channel pulse height analyzer and a coincidence circuit. Pulses from the two detector units entered the coincidence circuit. Furthermore, one of the detectors gave pulses to the single channel analyzer, while pulses from the other were fed into the multi-channel analyzer. The output pulses from the coincidence circuit and from the single channel analyzer were further fed to a coincidence circuit in the multi-channel analyzer, which was thus gated for the input pulses.

In the coincidence measurements, the single channel analyzer was adjusted to accept pulses giving rise to the peaks at 0.63 MeV, 0.87 MeV, 2.4 MeV and 2.9 MeV.

In those experiments where pulses due to gamma rays of the energies 0.63 MeV and 0.87 MeV entered the channel, the $1\frac{3}{4}$-in × 1-in NaI(Tl) crystal was used as detector, giving pulses to the single channel analyzer. On the other hand, when the spectra in coincidence with the 2.4 MeV and 2.9 MeV gamma rays were studied, the 4-in × 4-in NaI(Tl) crystal was used for this purpose.

The coincidence spectrum in Fig. 3 is obtained with the channel selecting pulses due mainly to the 0.63 MeV gamma ray. The 2.9 MeV gamma ray is present while the 3.4 and the 2.4 MeV gamma rays are noticeably suppressed. Photo-peaks due to the 2.0 MeV and 1.8 MeV gamma rays seem also to be present, as are the 1.0 MeV and 0.87 MeV gamma rays. Furthermore, the relative intensities of these gamma rays seem to be roughly of the same order as in the singles spectrum. The photo-peak due to the 0.63 MeV gamma ray is strongly suppressed in the coincidence spectrum. The presence of this photo-peak must be mainly due to coincidence relations between the 0.63 MeV gamma ray and the 0.87 MeV and 1.0 MeV gamma rays, which entered the channel to a certain extent owing to Compton absorption.

Fig. 4 shows the spectrum of the gamma rays which are in coincidence mainly with the 0.87 MeV gamma ray. It is seen that the part of the spectrum due to gamma rays with energies above 2.0 MeV is strongly depressed. The 2.0 MeV gamma ray is present as well as the 0.63 MeV and the 1.0 MeV gamma rays. The presence of the 0.87 MeV gamma ray in this spectrum seems to be largely due to coincidence relations between this gamma ray and the 1.0 MeV and the 2.0 MeV gamma rays entering the channel by Compton absorption.

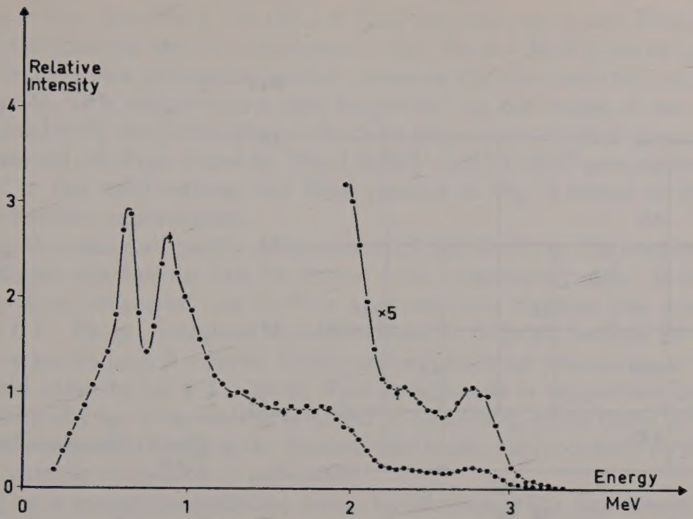

Fig. 3. Coincidence spectrum obtained when pulses constituting the peak at 0.63 MeV are allowed to enter the channel. The statistical errors are given for a few points.

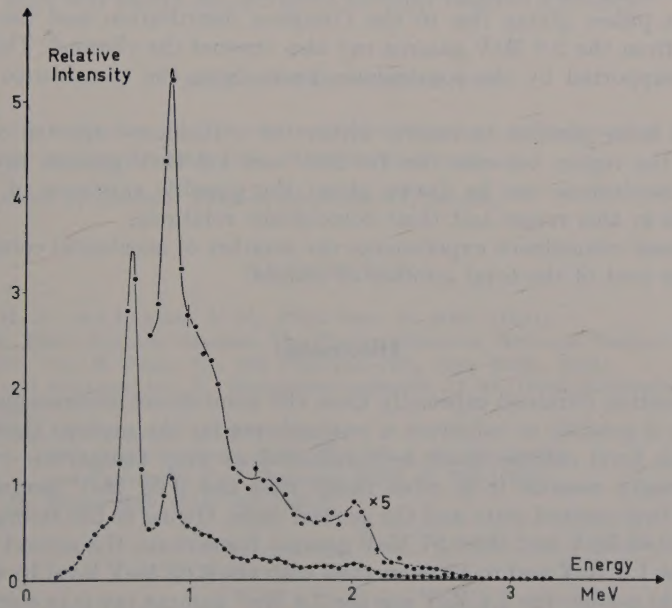

Fig. 4. Coincidence spectrum obtained when pulses constituting the peak at 0.87 MeV are allowed to enter the channel. The statistical errors are given for a few points.

When investigating the spectrum of the gamma rays in coincidence with the 2.9 MeV gamma ray, only one photo-peak is found, which is due to the 0.63 MeV gamma ray. This photo-peak is also the only one arising in the spectrum of the gamma rays in coincidence with the 2.4 MeV gamma ray. From intensity considerations it

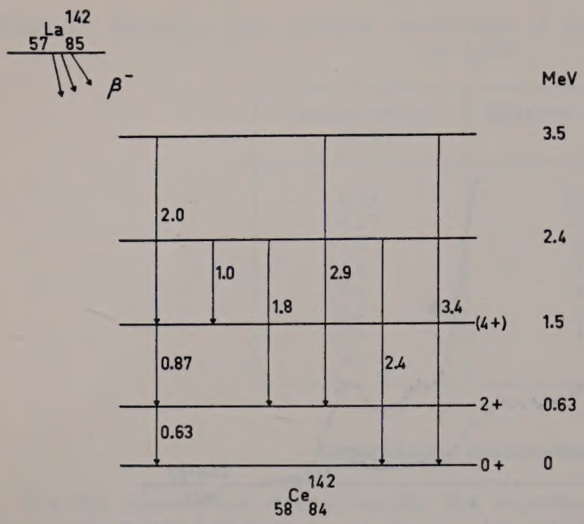

Fig. 5. Tentative level scheme of Ce^{142}.

seems in the latter case most probable to account for the presence of this peak by the fact that pulses giving rise to the Compton distribution and the overlapping escape peak from the 2.9 MeV gamma ray also entered the channel. This interpretation is also supported by the conclusions drawn from the coincidence spectrum in Fig. 3.

It has not been possible to resolve either the coincidence spectra or the singles spectrum in the region between the 1.0 MeV and 1.8 MeV gamma rays. Therefore no definite conclusions can be drawn about the possible existence of gamma rays with energies in this range and their coincidence relations.

In all of these coincidence experiments the number of accidental coincidences was below ten per cent of the total number of counts.

Discussion

The information obtained especially from the coincidence measurements reported above makes it possible to construct a level scheme for the nucleus Ce^{142} (cf. Fig. 5). However, this level scheme must be considered as very tentative.

From intensity reasons it is most likely that the 0.63 MeV gamma transition connects the first excited state and the ground state. Owing to the strong coincidence between the 0.63 MeV and the 0.87 MeV gamma transitions, the second excited state seems to be at 1.5 MeV and to be connected with the 0.63 MeV level by the 0.87 MeV gamma ray. As neither the 2.4 MeV nor the 3.4 MeV gamma ray is in coincidence with the 0.63 MeV gamma ray, but both of them according to half-life measurements belong to the decay of La^{142}, they must go to the ground state as indicated in Fig. 5. The 2.9 MeV gamma ray is in coincidence with the 0.63 MeV gamma ray but not with the 0.87 MeV gamma ray. This fact gives the 2.9 MeV gamma transition a rather unambiguous position in the decay scheme.

The remaining three gamma rays given in Table 1 are more uncertain as far as the energies and the relative intensities are concerned. Their position in the level scheme is also uncertain. As the 1.0 MeV gamma ray is not detectable in the spectrum of the gamma rays in coincidence with the 2.4 MeV gamma ray, it seems most probable that this gamma transition connects the third and the second excited level (cf. Fig. 5). This suggestion is also supported by the shape of the coincidence spectra obtained with the pulses due to the 0.63 MeV and 0.87 MeV gamma rays triggering the channel (cf. Figs. 3 and 4). The 1.8 MeV and 2.0 MeV gamma rays might be interchanged in the level scheme but their placing in Fig. 5 seems to give the best agreement with the experiments.

Concerning the spin and parity assignments of the levels in the even-even nucleus Ce^{142}, no definite conclusions can be drawn from our experiments. However, some indications will be discussed. As Ce^{142} is an even-even nucleus, the groundstate is classified as $0+$. From statistical considerations it is most natural to assume the first excited state to be a $2+$ level. Furthermore, it seems reasonable to assume the second excited state to be a $4+$ level. This assignment is supported firstly by the fact that practically no beta feeding is found to this level, while there is evidence for a strong beta component feeding the first excited state, and secondly by the fact that no 1.5 MeV gamma transition is observed.

According to a recent compilation made by Morinaga [7], the lowest odd-parity state, if any, in this case should have an excitation energy between 2 and 3 MeV. It seems not unreasonable that the 2.4 MeV gamma transition originates from such a state with odd parity according to its high relative intensity.

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